PFAS Exposure Assessment Technical Toolkit (PEATT) Pilot Project

Division of Environmental Health Epidemiology

December 2018

pennsylvania
DEPARTMENT OF HEALTH

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Executive Summary

Per- and polyfluoroalkyl substances (PFAS) are a large group of chemicals widely used in commercial and industrial processes. PFAS consist of a very strong carbon-fluorine bond that provides high thermal and chemical stability and prevents breakdown in the natural environment. Studies on the public health implications of PFAS are still in process, but results to-date have been inconsistent; there is evidence that PFAS contamination may pose risks to the developmental, immune, metabolic and endocrine health of those exposed. PFAS contamination was discovered in public drinking water supplies in Pennsylvania's Bucks and Montgomery counties that were linked to the operations in the nearby military bases. The Pennsylvania Department of Health (DOH) conducted biomonitoring of 235 randomly selected community members who live in any of the four public water system service areas surrounding two military bases as part of a pilot project to evaluate the PFAS Exposure Assessment Technical Tools (PEATT) developed by the Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR). DOH also collected data on demography, exposure and health conditions from the study participants using questionnaires. The pilot project was funded by the Association of State and Territorial Health Officials (ASTHO).

Serum samples were analyzed for 11 PFAS compounds. Only perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), perfluorohexanesulfonic acid (PFHxS) and perfluorononanoic acid (PFNA) were consistently detected in the serum samples of the study participants. The other seven PFAS compounds were detected in less than 15 participants. The average levels of PFOA, PFOS, PFHxS and PFNA among the study participants were 3.13, 10.24, 6.64 and 0.74 microgram per liter (ug/L), respectively. Overall, 75, 81, 94 and 59 percent of the study participants had levels exceeding the national average for PFOA (1.94 ug/L), PFOS (4.99 ug/L), PFHxS (1.35 ug/L) and PFNA (0.66 ug/L), respectively, and the levels in general increased with age. Though the difference was not statistically significant, males in the study had higher levels of PFOA, PFOS and PFHxS, whereas females had higher levels of PFNA. The serum PFAS levels increased with the length of residence in the area. Private well water users had higher levels of PFOA, PFOS and PFNA than public water users. However, the differences were not statistically significant. Estimated quantity of tap water consumed (self-reported) daily did not show a consistent relationship with serum PFAS levels. The study participants who reported ever working in the military base had higher levels (not statistically significant) of PFOA, PFOS and PFHxS compared to the other study participants. The most frequently reported health condition was elevated cholesterol level, followed by endocrine disruptions and cancer.

Background

PFAS include more than 3,500 man-made chemical compounds, widely used in consumer products and industrial applications. Some of the major uses that contribute to environmental release of these chemicals include firefighting training/response and industrial production of commercial household products with stain and water-repelling properties such as fabrics or Teflon. Landfills and wastewater treatment operations also contribute to environmental release

of PFAS. PFAS are very stable compounds that remain in the environment for a very long time and also tend to bioaccumulate. The biological half-life of some of the common PFAS compounds is estimated to range from two to 10 years (e.g., perfluorooctanoic acid [PFOA] two to four years, perfluorooctanesulfonic acid [PFOS] four to six years and perfluorohexanesulfonic acid [PFHxS] eight to 10 years). Biological half-life is the period of time it takes for a substance inside a living organism to be eliminated by half of its initial amount through normal biological processes. Humans are exposed to PFAS in many ways, including consumption of contaminated drinking water and certain foods (such as fish), contact with commercial products (e.g., food packaging), inhalation of residues in household dust and indoor air, and through occupational exposure. Measurable concentrations of PFAS are found in 97 percent of the general U.S. population (CDC, 2015). Of the PFAS, only a few have been studied for their human health impacts. Studies have indicated that PFAS may affect growth, learning, and behavior of infants and older children; lower a woman's chance of getting pregnant; interfere with the body's natural hormones; increase cholesterol levels; affect the immune system; and increase the risk of cancer (ATSDR, 2018).

Large scale contamination of drinking water sources by PFAS occurred in Pennsylvania and in many other states among communities near military bases where PFAS were used in firefighting exercises. These bases were routinely performing firefighting trainings using PFAS-containing aqueous film-forming foams (AFFF) for several decades. The use of AFFF in training exercises led to direct emissions of PFAS into surface and ground waters. Montgomery and Bucks counties in Southwestern Pennsylvania were the locations of two such large military bases.

Figure 1. Naval Air Warfare Center

Firefighters using AFFF

Figure 2. Horsham Air Guard Station

The former Naval Air Warfare Center (NAWC) in Warminster Township, Bucks County, Pennsylvania, (Figure 1) was used to research, develop and test naval aircraft systems, and was located near four of the 18 Warminster Municipal Authority (WMA) public water supply wells. PFAS compounds were detected in the WMA system in the summer of 2013. Further study was performed by the U.S. Environmental Protection Agency (EPA), and, as of September 2015, PFAS were detected in 93 out of the 100 private wells within a one to three-mile radius of the military site. Consequent to the detection of PFAS at or above EPA's Provisional Health Advisory Levels (PHAL) of 0.2 microgram per liter (ug/L) for PFOS and 0.4 ug/L for PFOA, all contaminated public water system wells were taken out of service by July 2014, and the Navy and EPA provided bottled water to all residents with contaminated private

wells. A subset of additional private wells with lower levels of PFAS within 25 percent of the PFOS or PFOA PHALs are being monitored through quarterly resampling. The U.S. Navy, EPA and WMA are currently implementing a long-term plan to address the PFAS groundwater contamination in the public water wells at the site.

The Horsham Air Guard Station (HAGS) in Horsham Township, Montgomery County, Pennsylvania (Figure 2), located a few miles away from NAWC is on a 1,200-acre site that was shared with the Naval Air Station Joint Reserve Base (NASJRB) until the U.S. Navy departed in 2011. Military operations began during the 1920s, and the base is currently operated under the Pennsylvania Air National Guard. The firefighting training area is in the southcentral region of the NASJRB and was used from 1942 to 1975. The AFFF used on the HAGS base resulted in PFAS contamination of two nearby public water systems — the Horsham Water and Sewer Authority (HWSA) and the Warrington Township Water and Sewer Department (WTWSD). In July 2014, two of the 15 HWSA wells were above the PHAL for a specific PFAS (PFOS) and were taken out of service. In October 2014, three of the nine WTWSD wells with levels above the PHAL for PFOS were taken out of service.

In May 2016, EPA released a lifetime health advisory level (LHAL) of 70 parts per trillion (PPT) or 0.07 ug/L for PFOS and PFOA combined. The public water systems immediately removed additional wells from service that had PFAS levels above the new health-based standard. The remaining wells retested below the LHAL. Additional private well owners whose wells retested above the LHAL were supplied with bottled water.

AFFF containing PFAS have been available since the mid-1960s; therefore, it is likely that the communities near these bases have been exposed to PFAS in their drinking water at levels above the EPA's health-based standards for nearly 50 years. The affected communities are very concerned about the potential adverse health effects and have been actively requesting more activity on the part of public health officials, public environmental officials and other responsible partners. Affected communities in Pennsylvania and elsewhere have been calling for biomonitoring (i.e., taking blood or urine samples to measure PFAS levels in the body) to test for suspected exposure. Citizens are concerned that they may have been directly impacted by the contamination and may be at risk for negative health effects. In response to these requests, CDC and the Agency for Toxic Substances and Disease Registry (ATSDR) developed a toolkit, PFAS Exposure Assessment Technical Tools (PEATT), in 2017 to provide assistance to jurisdictions in conducting biomonitoring for PFAS. This toolkit provides detailed instructions on biomonitoring and exposure assessment at community levels. In 2018, CDC established funds through ASTHO to support two jurisdictions to implement pilot biomonitoring projects to evaluate the PEATT. The Pennsylvania Department of Health (DOH) was one of the states that received funds to implement the PEATT pilot project. DOH selected communities with elevated PFAS exposure because of their proximity to the two military bases in southeastern Pennsylvania. The specific goals of the project were (1) to implement the PEATT on a pilot scale in a large affected community in Pennsylvania to assess the serum levels of PFAS among selected residents from all sources, (2) learn lessons to facilitate potential future large-scale biomonitoring for PFAS, and (3) provide feedback to ATSDR to improve future revisions of the PEATT.

Methods

Considering that drinking water was the major medium of exposure, DOH implemented the PEATT Pilot Project in Montgomery and Bucks counties in the water service areas under the HWSA, WMA, WTWSD and the WTWSD/North Wales Water Authority (NWWA). This total area has 32,595 households with a population of 84,184 based on the 2010 census. DOH used a one-stage cluster sampling of households for biomonitoring as indicated in the PEATT. This geographical area represents the water distribution area surrounding NAWC and HAGS. Individuals who were currently living and had lived in the above-mentioned water service areas prior to June 1, 2016 (this date refers to when all public water wells in the area having PFOS/PFOA at or above EPA's LHAL level of 70 PPT were taken out of service and residents with private wells having levels above EPA's LHAL started receiving bottled water), were considered eligible to be included. The study goal was participation by 500 individuals from 350 households (estimated 2.6 individuals per household). These households were selected randomly from the list of all households within the service areas of the above-mentioned public water systems (sampling frame), and all household members, including children (3 to 17 years), were recruited for biomonitoring. The DOH Institutional Review Board approved the pilot study protocol.

Initial letters of interest along with eligibility forms were sent to 350 households in the affected region, including the towns of: Ambler, Horsham, Hatboro, Chalfont, Warminster, Jamison, Warrington and North Wales. The eligibility form asked one individual in the household to identify the number of eligible adults and children currently living in the home who had lived there prior to July 1, 2016 (prior to the remediation). The first mass mailing was sent on May 1, 2018. Reminder letters were sent on May 18 to households that did not respond to the initial letter. Two hundred and thirty-seven households responded by returning the eligibility form (44 percent household level response rate). A second random sampling was performed, and eligibility forms were sent to another 250 additional households on May 25, and 122 responded (48.8 percent response rate). Overall 276 households responded — a household level response rate of 46 percent. This resulted in 584 individuals, including 113 children (3-17 years), being interested and eligible to participate. Among the 584 potential participants, 235 completed the paperwork (informed consent and questionnaire) and provided blood samples (40 percent response rate), including 26 children (3-17 years old). These participants represented 118 households out of the 276 households that responded.

Exposure History and Demographic Data Collection

All selected households were sent a participation packet through the U.S. postal service. This packet included a cover letter, consent forms for each eligible and interested person in the household, information sheets on PFAS, a Physician Interim Guidance document (from the PEATT), an instruction sheet explaining how to make a clinic appointment for blood draw, and questionnaires for each member of the household. The questionnaires asked about demographic factors, drinking water habits, years of residence in current and prior area homes, health conditions, pregnancy status if female, workplace locations, and water sources. Child questionnaires included questions about school/daycare water sources, as well as breastfeeding and formula consumption. Once questionnaires and signed consent forms were

returned, participants could schedule appointments to have their blood samples drawn at Montgomery and Bucks county health department clinics.

Blood Sample Collection and Serum Extraction

DOH collaborated with the local health departments of Montgomery and Bucks counties, the Pennsylvania State Bureau of Laboratories (BOL) and New York State Health Department in blood sample collection and analysis. Wadsworth Laboratory in the New York State Department of Health is a Clinical Laboratory Improvement Amendments (CLIA) certified laboratory accredited to test blood samples for PFAS. This laboratory provided testing and analysis of an 11-compound panel of PFAS. The laboratory tested for the following compounds:

- Perfluorobutanesulfonic acid (PFBS)
- Perfluorohepatnoic acid (PFHpA)
- Perfluorohexanesulfonic acid (PFHxS)
- Perfluorononanoic acid (PFNA)
- Perfluorooctanoic acid (PFOA)
- Perfluorooctanesulfonic acid (PFOS)
- Perfluorodecanoic acid (PFDeA)
- Perfluoroundecanoic acid (PFUA)
- Perfluorododecanoic acid (PFDoA)
- Perfluorooctane sulfonamide (PFOSA)
- 2-(N-Methyl-perfluorooctane sulfonamido) acetic acid (MeFOSAA)

Blood draw clinics were organized by the county health departments from May through September 2018. County personnel separated the serum and stored it, according to laboratory protocol, prior to transporting the samples to BOL's Lionsville facility. BOL personnel received the samples and sent them to Wadsworth Laboratory in batches of 20 or more, following the protocols for interstate transfer and packaging of biological specimens. Serum samples were collected in bar-coded vials with no identifiable information about the participant. DOH linked the serum test results to the correct participants using barcodes and reconfirmed the linkage using a unique identification system established for this.

Data Analysis

Data on demography, exposure, occupation and health conditions from the questionnaires were transcribed into a database. Prior to analysis, the questionnaire data and PFAS test result data were merged, and quality checks were performed. The data were analyzed (proc surveymean and proc surveyreg, using log-transformed PFAS values) for (1) generating summary statistics (average/geometric mean, confidence interval, median and range) and (2) understanding the relationship between demographic, exposure and occupational variables and serum concentration of PFAS. Given the small sample size (n=26) for children (3-17 years), separate detailed analysis for this age group was not performed. When test results were below the laboratory's limit of detection (LOD) of 0.5 nanogram per milliliter (ng/mL), the value was estimated by dividing the LOD by the square root of two. All analyses were performed using SAS v 9.4 (SAS Institute, Carry, NC). A p-value <0.05 was considered

statistically significant in all analyses. P-values are calculated based on the hypothesis or assumption that there is no difference between the groups compared. In simple terms the lower the p-value, the more confident we are that the alternate hypothesis is true—that there is significant difference between the groups compared. Individual results were mailed to the participants, as soon as their results were ready, along with a comparison of individual results with the average and 95th percentile values at the national level for the corresponding age group. A second letter was sent in November 2018 to all participants when all results were available, comparing individual results with the community average and 95th percentile values for the corresponding age group both at the community and national levels.

Results

A total of 235 individuals submitted blood samples for testing from May to September 2018. Table 1 presents the demographic and exposure characteristics of the study participants — 12 (5.1 percent) were children aged 3-11 years, 19 (8.1 percent) were aged 12-19 years and 204 (86.8 percent) were aged 20 years or older. The majority of the individuals tested were females (n=131, 55.7 percent). Approximately 66 percent (n=155) had some college or higher level of education, with 29.4 percent (n=69) having an annual household income of >$75,000 (data not shown). However, information on household income was unavailable for the majority of the study participants (n=144, 61.3 percent). Approximately 30 percent of the study participants (n=71) had more than one prior residence in the study area (data not shown). In addition, 54.1% of the participants had been living in their current addresses for more than 20 years (n=110), and 81.9 percent had lived there 10 years or more. Public water was the drinking water source for a majority of the participants at their current residences (n=193, 82.1 percent). Thirty-seven percent of participants (n=87) consumed an average of four to seven cups of tap water daily, and 18.7 percent consumed eight or more cups of tap water daily (n=44). Twenty-four (11.7 percent) adult participants reported ever working on the military base.

Table 1: Demographic and Exposure Characteristics of Participants (n=235)

Characteristic	Number of Participants	Percentage
Age group (years)		
3 to 11	12	5.1
12 to 19	19	8.1
20+	204	86.8
Sex		
Male	104	44.3
Female	131	55.7
Education level		
Grades 1-8	1	0.43
Grade 12 or GED	42	17.87
College or more	155	65.96
Unknown	37	15.74
Length of residence at the current address (20 years or older), n=204		
Less than 5 years	20	9.8
5 to 9 years	16	5.9
10 to 19 years	57	27.8
20 to 29 years	61	30.2
30 to 39 years	19	9.3
40+ years	30	14.6
Unknown	1	0.5
Source of drinking water (current residence)		
Public Water	193	82.1
Private Well	20	8.5
Other (includes missing information and bottled water users)	22	9.4
Estimated tap water consumption (cups per day)- current address		
Less than 4	48	20.4
4 to 7	87	37.0
8+	44	18.7
Unknown	56	23.8
Ever employed on a military base (20 years or older), n=204		
Yes	24	11.7
No	178	86.80
Unknown	2	0.98

Among the 11 PFAS tested for, only four compounds (PFOS, PFOA, PFHxS and PFNA) were detected consistently. PFOS was detected in all 235 participants. Two hundred and thirty-two, 233 and 185 participants had PFOA, PFHxS and PFNA in their serum samples, respectively. PFOS, PFOA and PFHxS together were detected in 232 of the 235 participants. PFOA, PFOS, PFHxS and PFNA together were detected in 185 of the 235 participants, meaning 79 percent of the residents had all four PFAS compounds in their blood samples. In addition to these four compounds, MeFOSAA and PFDeA were present in nine and 14 participants, respectively. The

serum level ranges for the four compounds detected in less than 15 participants were PFDeA (n=14) 0.51-0.90 ug/L, MeFOSAA (n=9) 0.52-1.6 ug/L and PFUA (n=8) 0.51-0.95 ug/L. PFHpA was detected in one participant. PFBuS, PFDoA and PFOSA were not detected in the blood samples of any study participant. Table 2 below presents the averages (geometric means), confidence intervals, median and ranges of PFOS, PFOA, PFHxS and PFNA reported in the serum samples of the participants in this study along with the averages and confidence intervals for these compounds reported at the national level. Overall, 75, 81, 94, and 59 percent of the study participants had levels exceeding the national average for PFOA (1.94 ug/L), PFOS (4.99 ug/L), PFHxS (1.35 ug/L) and PFNA (0.68 ug/L), respectively.

Table 2: Selected PFAS Levels (ug/L) in the Community (n=235) and at the National Level*

PFAS Compound	Community Results				NHANES Results (2013-2014)	
	Average	95% Confidence Interval	Median	Range	Average	95% Confidence Interval
PFOA	3.13	2.81-3.50	3.06	0.55-24.8	1.94	1.76-2.14
PFOS	10.24	8.86-11.83	9.86	1.02-105.00	4.99	4.50-5.52
PFHxS	6.64	5.51-7.99	6.61	0.54-116.00	1.35	1.20-1.52
PFNA	0.74	0.67-0.80	0.76	0.50-2.56	0.68	0.61-0.74

NHANES data: The National Report on Human Exposure to Environmental Chemicals, Updated Tables, Volume 1, March 2018, is available at: https://www.cdc.gov/exposurereport/.
*NHANES includes participants aged 12 years and above. NHANES sample sizes were 2,165 for PFOA and PFOS and 2,168 for PFHxS and PFNA. Range excludes values <LOD.

The average levels of PFOA, PFOS, PFHxS and PFNA among participants of the study were higher than the average levels reported at the national level based on the 2013-2014 NHANES survey. The distributions of serum PFAS levels among community members are presented in Figure 3 to Figure 6. The x-axes in Figure 3 to Figure 6 represent the study participants, not in any particular order.

Figure 3: Distribution of the Serum Levels (ug/L) of PFOA Among Community Members

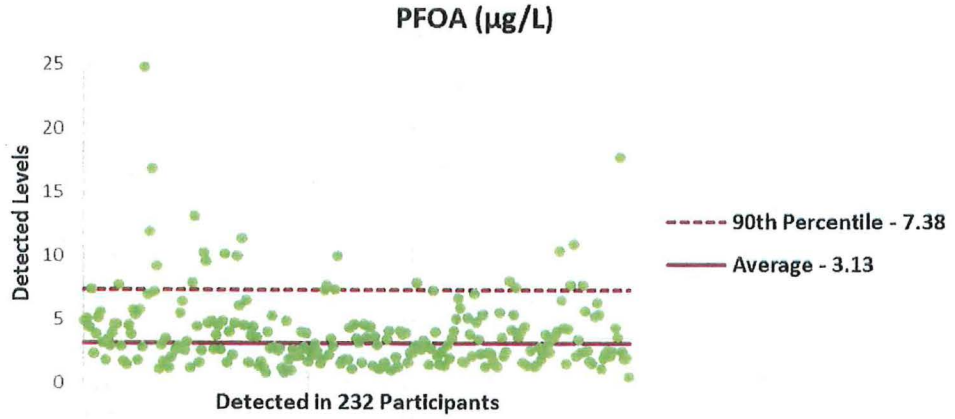

Figure 4: Distribution of the Serum Levels (ug/L) of PFOS Among Community Members

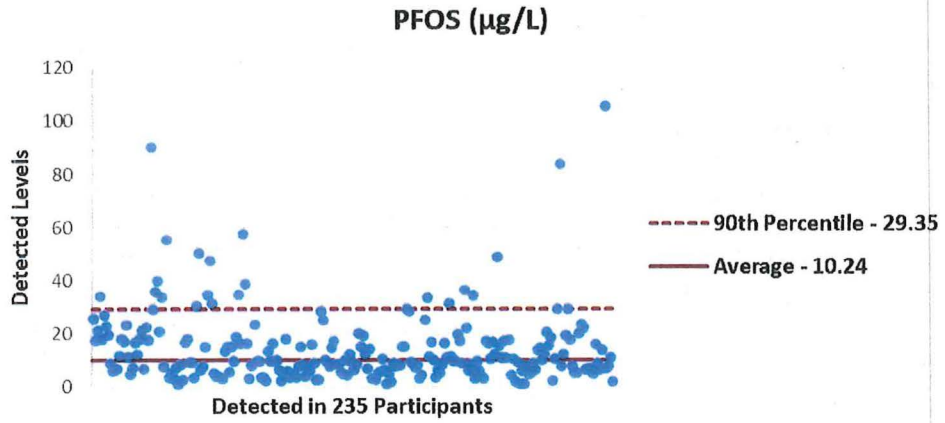

Figure 5: Distribution of the Serum Levels (ug/L) of PFHxS Among Community Members

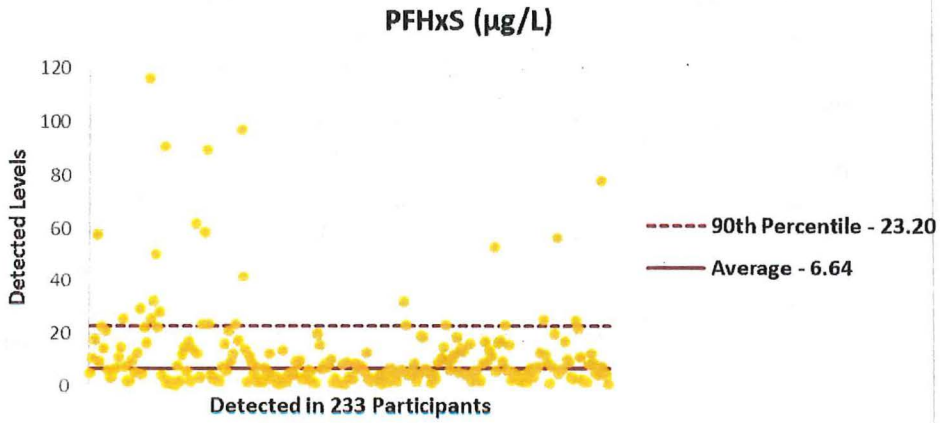

Figure 6: Distribution of the Serum Levels (ug/L) of PFNA Among Community Members

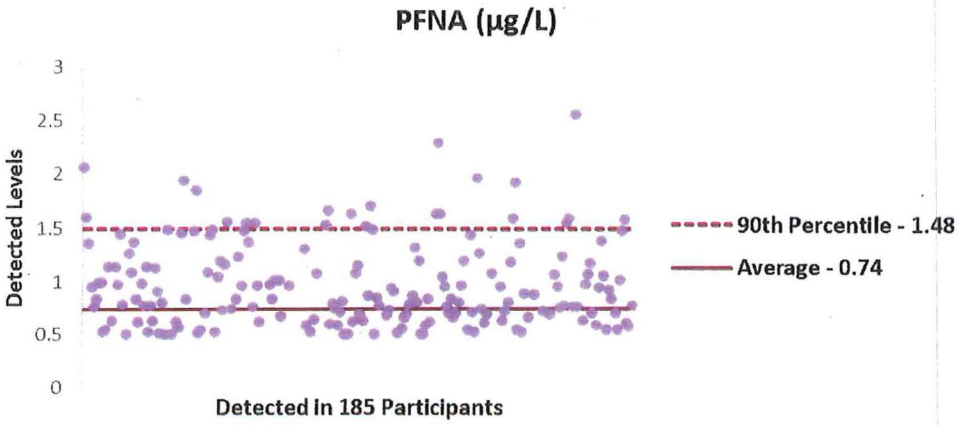

Table 3 – Table 8 compare the levels of PFOA, PFOS, PFHxS and PFNA among study participants by age, sex, length of residence at current address, amount of water consumed at current address, water source at current address, and employment on the military base (if ever employed). Table 9 presents the frequencies of various health conditions (grouped into growth/learning/behavior, women's reproduction, endocrine disruptions, elevated cholesterol levels and cancer) reported by the study participants.

The levels of PFOA, PFOS, PFHxS and PFNA among different age groups within the community differed significantly ($P<0.05$ for all). In general, the levels of these four PFAS compounds among the study participants increased with age (Table 3), and for nearly all age groups, community results exceeded NHANES results for each compound. The exception is a lower result for PFNA among 3- to 11-year-olds and 12- to 19-year-olds. In our study, males had higher PFAS levels than females except for PFNA (Table 4), whereas, at the national level, males had higher levels than females for all these four compounds. However, the difference in PFAS levels between male and female community members in our study was not statistically significant ($P>0.05$ for all four compounds).

Table 5 and Table 5a present the PFAS levels among the participants (20 years and older) by their length of residence at the current address in the community. Testing showed significant difference in levels of PFOA, PFOS, PFHxS and PFNA ($P <0.05$ for all) among participants with different residential histories. Generally, the longer the residence time, the higher the concentration of PFAS found in participants' blood. There was some inconsistency in that residents with a residential history of 10-19 years in the community showed generally higher PFOS and PFNA levels than those who have been living in the area for 20-29 years. Those who lived in the community for less than five years had slightly higher levels of PFOS and PFNA than those who lived in the community for five to nine years (Table 5). However, this inconsistency was not visible when the data were analyzed by grouping the participants into those with <10 years, 10-39 years and 40+ years of residential history at the current address in the community (Table 5a).

Table 3: Selected PFAS Levels (ug/L) in the Community (n=235) and at the National Level by Age Group*

PFAS Compound	Community Results						NHANES Results (2013-2014)					
	Age						Age					
	3 to 11 years		12 to 19 years		20+ years		3-11 years		12-19 years		20+ years	
	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval
PFOA	2.02	1.66-2.45	2.17	1.70-2.78	3.32	2.96-3.72	1.92	1.75-2.12	1.66	1.50-1.84	1.98	1.79-2.19
PFOS	3.91	3.02-5.07	5.18	3.93-6.83	11.50	10.08-13.12	3.88	3.53-4.27	3.54	3.17-3.96	5.22	4.70-5.81
PFHxS	2.00	1.24-3.23	2.99	2.19-4.09	7.63	6.41-9.08	0.84	0.76-0.94	1.27	1.06-1.53	1.36	1.21-1.53
PFNA	0.39	0.35-0.43	0.57	0.43-0.76	0.78	0.72-0.84	0.79	0.68-0.93	0.60	0.49-0.73	0.69	0.63-0.75

NHANES data: The National Report on Human Exposure to Environmental Chemicals, Updated Tables, Volume 1, March 2018 is available at: https://www.cdc.gov/exposurereport/.

Note: NHANES sample sizes were 639 (3- to11-year-olds) for all four compounds, 401 for PFOA and PFOS and 402 and for PFHxS and PFNA for 12-19 year-olds, 1,764 for PFOA and PFOS, and 1,766 for PFHxS and PFNA for those aged 20+ years.

*Significant (P<0.05) difference in levels of all four PFAS among age groups within the community

Table 4: Selected PFAS Levels (ug/L) in the Community (n=235) and at the National Level by Sex

PFAS Compound	Community Results				NHANES Results (2013-2014)			
	Male		Female		Male		Female	
	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval
PFOA	3.27	2.86-3.73	3.03	2.66-3.45	2.29	2.09-2.50	1.66	1.48-1.87
PFOS	11.03	9.15-13.30	9.65	8.27-11.27	6.36	5.62-7.20	3.96	3.60-4.35
PFHxS	7.54	5.96-9.54	5.99	4.88-7.36	1.84	1.59-2.12	1.01	0.91-1.12
PFNA	0.73	0.66-0.81	0.74	0.67-0.82	0.76	0.68-0.85	0.6	0.55-0.66

NHANES data: The National Report on Human Exposure to Environmental Chemicals, Updated Tables, Volume 1, March 2018 is available at: https://www.cdc.gov/exposurereport/.

Note: NHANES includes participants aged 12 years and above. NHANES sample sizes were 1,031 (male) and 1,134 (female) for PFOA and PFOS and 1,032 (male) and 1,136 (female) for PFHxS and PFNA.

Table 5: Selected PFAS Levels (ug/L) in the Community (n=203) by Length of Residence*

PFAS	Less than 5 years		5 to 9 years		10 to 19 years		20 to 29 years		30 to 39 years		40+ years	
	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval
PFOA	2.46	1.77-3.43	2.73	1.87-3.99	3.04	2.49-3.71	3.26	2.57-4.14	4.28	3.20-5.73	4.76	3.79-5.99
PFOS	8.24	5.30-12.81	7.78	4.56-13.26	11.09	8.86-13.90	10.81	8.49-13.76	13.58	10.13-18.20	20.13	15.74-25.73
PFHxS	4.92	2.74-8.86	6.40	3.58-11.43	5.85	4.26-8.05	7.82	5.65-10.81	9.60	6.92-13.31	15.88	11.18-22.54
PFNA	0.75	0.58-0.96	0.64	0.51-0.80	0.80	0.70-0.92	0.69	0.61-0.78	0.83	0.65-1.06	1.09	0.88-1.35

Note: Excludes participants <20 years of age and one respondent with missing information
*Significant difference in levels of all four PFAS (P<0.05 for all) among groups with different residence lengths within the community

Table 5a: Selected PFAS Levels (ug/L) in the Community (n=203) by Length of Residence*

PFAS Compound	Less than 10 years		10 to 39 years		40 years and above	
	Average	95% Confidence Interval	Average	95% Confidence Interval	Average	95% Confidence Interval
PFOA	2.58	2.1-3.17	3.29	2.85-3.80	4.76	3.79-5.99
PFOS	8.03	6.03-10.69	11.28	9.70-13.12	20.13	15.74-25.73
PFHxS	5.53	3.93-7.77	7.13	5.79-8.78	15.88	11.18-22.54
PFNA	0.70	0.60-0.81	0.75	0.69-0.83	1.09	0.88-1.35

Note: Excludes participants <20 years of age and one respondent with missing information
*Significant difference in levels of all four PFAS (P<0.05 for all) among groups with different residence lengths within the community

Table 6 presents the PFAS levels among study participants by the estimated quantity of tap water consumed per day at the current residence. Those who consumed less than four cups per day had lower PFAS levels than those who consumed four to seven cups daily. However, those who consumed four to seven cups of water daily had higher PFAS levels than those who consumed eight or more cups of water daily. Statistically significant differences in levels of PFOA and PFNA (P<0.05 for both) were observed among groups of participants who consumed different amounts of tap water daily.

Table 6: Selected PFAS Levels (ug/L) in the Community (n=235) by Estimated Daily Tap Water Consumption*

PFAS Compound	Less than 4 cups			4-7 cups			8 + cups			Unknown		
	Average	95% Confidence Interval	Range	Average	95% Confidence Interval	Range	Average	95% Confidence Interval	Range	Average	95% Confidence Interval	Range
PFOA	2.83	2.39-3.36	0.88-13.10	3.72	3.20-4.32	1.08-11.90	3.58	2.87-4.48	1.13-24.80	2.36	1.88-2.97	0.55-17.80
PFOS	10.29	8.16-12.97	1.94-50.70	12.00	9.90-14.54	1.10-83.50	9.54	7.17-12.70	1.03-90.10	8.43	6.24-11.39	1.02-105.00
PFHxS	5.84	4.20-8.13	0.80-62.00	7.82	5.98-10.23	0.94-89.60	7.41	5.21-10.54	0.93-116.00	5.26	3.70-7.47	0.54-90.70
PFNA	0.72	0.62-0.85	0.51-2.29	0.84	0.75-0.93	0.50-2.06	0.76	0.64-0.90	0.50-2.56	0.59	0.49-0.71	0.51-1.96

Note: Unknown category includes 7 individuals who reported never using tap water. Range excludes <LOD.
*Significant difference in levels of PFOA and PFNA (P<0.05 for both) among groups with different quantities of tap water consumption within the community.

Those reported using private wells as their drinking water source in the study had higher levels of PFOA, PFOS and PFNA in comparison to those using public water as the drinking water source (Table 7), however, the levels were not significantly different (P >0.05 for all).

Table 7: Selected PFAS Levels (ug/L) in the Community (n=213) by Drinking Water Source

PFAS Compound	Public water			Private Well		
	Average	95% Confidence Interval	Range	Average	95% Confidence Interval	Range
PFOA	3.21	2.84-3.64	0.55-24.80	3.26	2.35-4.52	1.52-7.91
PFOS	10.25	8.70-12.09	1.02-105.00	11.55	8.34-15.99	4.93-29.4
PFHxS	7.02	5.72-8.62	0.54-116.00	6.19	3.22-11.93	1.09-32.00
PFNA	0.73	0.66-0.80	0.50-2.56	0.79	0.62-1.00	0.50-1.62

Note: This data excludes users of bottled water (n=14) and missing information (n=8). Range excludes <LOD.

Analysis of PFAS levels by employment location indicated that participants who worked on the military base (if ever employed) showed higher levels of PFOA, PFOS, and PFHxS, but not PFNA (Table 8): however, the differences in levels were not statistically significant (P>0.05 for all).

Table 8: Selected PFAS Levels (ug/L) in the Community (n=204) by Employment (if ever Employed) in Military Base

PFAS Compound	Ever employed on a military base					
	Yes			No		
	Average	95% Confidence Interval	Range	Average	95% Confidence Interval	Range
PFOA	3.52	2.69-4.61	1.21-16.8	3.30	2.91-3.75	0.55-24.80
PFOS	12.90	9.36-17.78	2.53-57.8	11.36	9.84-13.12	1.02-105.00
PFHxS	10.32	6.79-15.69	1.01-96.9	7.33	6.07-8.86	0.54-116.00
PFNA	0.77	0.62-0.94	0.51-1.58	0.79	0.72-0.86	0.50-2.56

Note: Range excludes <LOD.

We also looked at the demographic and exposure characteristics of a subgroup (n=25) of the study participants with at least two of the four consistently detected PFAS compounds at serum levels higher than the 90th percentile value of the community results (data not shown). The 90th percentile values were 7.38, 29.35, 23.20 and 1.48 ug/L for PFOA, PFOS, PFHxS and PFNA, respectively. The average age of the community members in this group was 61 years (range: males 48-76 years, females 20-81 years). Twenty-two of the individuals in this group (88 percent) lived in this community for 18 years or longer and had used public water. Five of the 25 individuals (20 percent) reported ever working on a military base.

The study participants were asked to report up to 10 health conditions they experienced and/or diagnosed with. Eighty-six participants (36.6 percent) did not report any health condition, 128 participants (54.5 percent) reported one to four conditions and 21 participants (9 percent) reported five or more health conditions. Among those who reported at least one health condition (n=149), 63 were males and 111 were above 50 years of age (data not shown). Table 9 presents the frequencies of various health conditions reported by the study participants, grouped into five major categories of health effects reported to be associated with PFAS exposure in literature. Ninety-four participants reported at least one health condition belonging to one of these categories, with 23 of them reporting two or more health conditions.

Table 9: Frequencies of Health Conditions Reported by Study Participants*

Health Conditions	Frequency
Growth-related	11
Women's reproduction	12
Endocrine disruptions	26
Cancer	24
Elevated cholesterol	49

*Does not include other conditions that could not be grouped into the categories

The most frequently reported health condition was elevated cholesterol level, followed by endocrine disruptions and cancer. A comparison of the number of reports of elevated cholesterol levels in relation to the median PFAS levels (median values for each PFAS are presented in Table 2) indicated a higher number of elevated cholesterol reports with higher (≥ median) levels for each of the four PFAS compounds (data not shown). Likewise, a higher number of reports of endocrine disruptions was associated with higher levels (≥ median) of PFOA and PFHxS. A higher number of cancer reports was associated with ≥ median levels of PFOA and PFNA (data not shown).

Discussion

Elevated levels of PFAS observed among the community members in the current study are comparable to levels reported in other communities with PFAS contaminated drinking water. New Hampshire residents exposed to drinking water contaminated with PFAS from a nearby military base showed an average community level of 3.09 µg/L for PFOA and 8.59 µg/L for PFOS (Daly *et al.*, 2018). In Minnesota, residents exposed to drinking water contaminated with PFAS from industrial sources had an average community level of 17 µg/L for PFOS. The PFAS compounds consistently found in this community study are also similar to the ones reported in another study (Landsteiner *et al.*, 2008).

A comparison of PFAS levels among age groups showed that levels of PFOA, PFOS, PFHxS and PFNA increased with age (Table 3). This is consistent with other studies that examined PFAS levels compared to age category, particularly with PFOS. However, some studies (e.g., Eriksson *et al.* 2017) have shown higher levels of PFOA in younger age groups. In contrast to the levels and pattern reported nationally, the levels of PFOS and PFHxS in the current study increased dramatically with increasing age.

In our study, males had higher PFAS levels than females except for PFNA (Table 4), though the differences were not statistically significant. Other studies (Jain, 2018 and Daly *et al.*, 2018) have also reported higher PFAS levels among males. The lower levels found in females is often attributed to female elimination routes such as breast feeding and menstruation. Also, at the national level the difference in PFAS levels among males and females was more marked than levels observed in the current study, probably owing to continued high level exposure in the community through drinking water.

Our results indicated a strong association between participants' length of residence and PFAS serum levels (Table 5), with longer residence time corresponding to higher PFAS concentrations in participants' blood in general. Exceptions were the groups with less than five years of residential history and those with 10-19 having higher levels for PFOS and PFNA than groups with 5-9 and 20-29 years of residential history respectively — an inconsistency that disappeared when residential length was regrouped to represent the groups with shorter versus longer residential histories (Table 5a).

The estimated amount of tap water consumed was found to be associated with serum PFAS levels in our study (Table 6); those who consumed less than four cups of tap water daily had lower PFAS levels than those who consumed four to seven cups daily. However, those who consumed eight cups or more of tap water had less PFAS in their blood samples than those who consumed four to seven cups daily. This relationship could not be explained with the available data, as there are several other sources of PFAS in the environment. Urine has been suggested to be a pathway of excretion of PFAS (Zhang *et al.*, 2015), and the observed relationship may partially be explained by the higher urinary excretion of PFAS by those who drink eight cups or more of water daily.

The users of private wells for drinking water had higher (not statistically significant) levels for PFOA, PFOS and PFNA compared to public water users (Table 7). It is to be noted that the quantity of tap water consumption, the source of drinking water and length of residence in our analyses were assessed based on current residence of the participants. Approximately 30 percent of the study participants (n=71) reported having more than one prior residence in the study area.

Our results also indicated higher, though not statistically significant, PFAS levels, except for PFNA, among those who reported being ever employed on the military base (Table 8). AFFF used in firefighting exercises at the base was the primary source of PFAS contamination. PFNA is not as predominant a compound as PFOS, PFOA or PFHxS in AFFF. Our analysis of the self-reported cases of various conditions indicated higher frequencies of elevated cholesterol levels, endocrine disruptions and cancer associated with higher serum levels of PFAS, as reported in many previous epidemiologic studies.

Although our analyses indicated some difference in PFAS levels in terms of demographic and exposure variables, it is important to note that the analyses have not been adjusted for potential confounders in the interest of simplicity. According to EPA (EPA, 2016a, 2016b), the dominant source of human exposure to PFOA and PFOS is expected to be from the diet; indoor dust from carpets and other sources also is an important source of exposure, especially for children. EPA uses a relative source contribution of 20 percent from drinking water for calculating health advisory levels for PFOA and PFOS in order to allow for other exposure sources, such as dust, diet and air. Although drinking water was contaminated in the current scenario the importance of other sources of PFAS exposure cannot be ignored. Therefore, it is not always possible to link an observed higher serum PFAS levels to drinking water without knowing all other exposure sources.

The half-lives of these compounds range from two to 10 years. Therefore, participants' blood levels were likely higher prior to 2016. PFAS levels in blood are declining overall across the nation. Although PFOA and PFOS were phased out of production starting in 2002 and general blood levels of most PFAS are declining, there are still many alternative PFAS compounds replacing PFOA and PFOS. These alternative compounds and mixtures when released into the environment can still combine and change into PFOA, PFOS and PFNA (Buck *et al.* 2011).

Conclusions

This pilot study involving residents in the Warminster, Warrington and Horsham communities showed that participants had elevated levels of PFAS compounds compared to the U.S. general population. This is consistent with other studies involving residents in communities with drinking water containing PFAS compounds at levels above the EPA's recommended LHAL of 70 PPT. This pilot study tested levels of 11 PFAS compounds and consistently found four PFAS compounds (PFOA, PFOS, PFHxS and PFNA) in the blood samples of the study participants. Overall, 75, 81, 94, and 59 percent of the study participants had levels exceeding the national average for PFOA (1.94 ug/L), PFOS (4.99 ug/L), PFHxS (1.35 ug/L) and PFNA (0.66 ug/L), respectively. The other seven PFAS compounds were detected in fewer (less than 15)

participants. In light of the fact that, nationally, PFAS levels in blood are declining steadily, it is likely that the PFAS levels were significantly higher in the years prior to this 2018 testing. Overall, PFAS levels increased with the age of participant as well as length of residence in the community. Males, private well water users and those who ever worked on the military base also had higher PFAS levels, though the increases in levels were not statistically different from the comparison groups (females, public water users and those who never worked on the military base, respectively).

Limitations and Challenges

Sample size and response rate: The goal and original estimated sample size for this study was 500. However, only 235 participants could be recruited. Of the 600 households contacted, 276 responded (46 percent response rate). Only 26 children (3-17 years) could be included in the study, limiting the scope of any meaningful analysis of the data for this age group.

Exposure assessment: Information on all potential sources of exposure could not be collected in this study. The measured serum PFAS levels would actually represent exposure from all sources.

Timing of the study: Testing of specimens took place approximately two years after contamination was discovered and remediated. Serum concentrations measured in our study likely do not capture the peak exposure levels. The seasonal timing of the testing was also a challenge due to participants' travel and summer vacations, particularly for the families with multiple children who have challenging schedules due to summer sports and extra-curricular camps.

Limited turnaround time: The project had an extremely short turnaround time of approximately nine months. Successful completion of all administrative steps and procedures within this timeframe was challenging. There are only a few laboratories in the country capable of analyzing PFAS in blood samples. DOH faced significant delay in finding a laboratory to start the project. A longer timeframe could have helped to increase the sample size and include more children.

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